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Factors Affecting Survival of Kokanees Stocked in Lake Pend Oreille, Idaho

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Abstract.-In 1987-1992, stockings of age-0 kokanees *Oncorhynchus nerka* in Lake Pend Oreille, Idaho, were evaluated to determine the contribution of hatchery fish to the age-0 population and their postrelease survival to autumn trawling, and to identify factors affecting survival of stocked fish. Fish were stocked at five locations in June or July and sampled with a midwater trawl near the end of their first growing season (late August-early September). Postrelease survival of hatchery kokanees averaged 23%, differed significantly among years, and ranged from 5 to 43% for individual release groups. From 1988 through 1991, survival of fry stocked in July was significantly higher than those stocked in June, but we could not detect a difference in survival among stocking locations. Survival of hatchery-reared kokanees was correlated with mean total zooplankton density during May-October, total zooplankton density at the time of stocking, density of *Diaphanosoma* sp., density of *Daphnia* spp., and size of *Daphnia* spp. High densities of zooplankton during 1985-1992 were associated with rapid development of the metalimnion (by June) and high numbers of May and June degree-days. Stocking of kokanees in Lake Pend Oreille did not restore the population to historical levels, and hatchery releases may only provide short-term benefits. We recommend stocking in July, but June stocking may be appropriate if zooplankton densities are sufficiently high to allow good survival of the fish.

Lake Pend Oreille supported the most popular fishery for kokanee *Oncorhynchus nerka* in Idaho from the *1940s* until the early *1970s* (Simpson and Wallace *1982).* Sport and commercial fisheries provided an average annual harvest of 1 million kokanees from *1951* to *1965* (Simpson and Wallace *1982).* Harvest of kokanees declined from *1965* to *1985* to a yearly average of less than 100,000 fish (Bowles et al. *1991).* In addition to providing an important fishery, kokanees are the primary forage for rainbow trout *O. mykiss* and bull trout *Salvelinus confluentus* in Lake Pend Oreille.

Several factors contributed to the decline of kokanees in Lake Pend Oreille. Water level fluctuations produced by hydropower development and flood control have adversely affected spawning success and survival of eggs and fry in redds. Albeni Falls Dam was completed in *1952* by the U.S. Army Corps of Engineers as part of the Bonneville Power Administration network (Figure 1). Cabinet Gorge Dam on the Clark Fork River, 24 km above the lake, was constructed by the Washington Water Power Co. (WWP) for power generation. Completion of this dam in *1952* blocked an important kokanee spawning run into the Clark Fork River and its tributaries. Declining abundance of kokanees may have been accelerated by commercial fishing. The establishment of opossum shrimp *Mysis relicta* in Lake Pend Oreille also may have affected kokanee adversely (Rieman and Falter *1981;* Bowles et al. *1991).*

Efforts to restore the kokanee fishery began during its initial decline. The Idaho Department of Fish and Game (IDFG) restricted kokanee sport harvest and terminated the commercial fishery in *1973.* Hatchery production of kokanees for Lake Pend Oreille was established in 1974 and helped stabilize population numbers. Before 1985, hatcheries could provide only 6 million to 8 million kokanee fry (about 50 mm) annually for Lake Pend Oreille, but research by IDFG personnel indicated that releases of up to 20 million fry annually might be necessary to restore the fishery to historic harvest levels of 750,000 fish per year (Rieman 1981). Therefore, Cabinet Gorge Hatchery was built on the Clark Fork River to meet these production goals. The hatchery, 4 km below Cabinet Gorge Dam, was operational by November 1985.

Stocking to supplement declining kokanee populations has become a common but largely untested management tool. Numerous factors influence the success of stocking programs, including habitat, productivity, hatchery capacity and limitations, stock status and productivity, brood source, and strategies used for spawning, rearing, and releasing fish. The purpose of this investiga-

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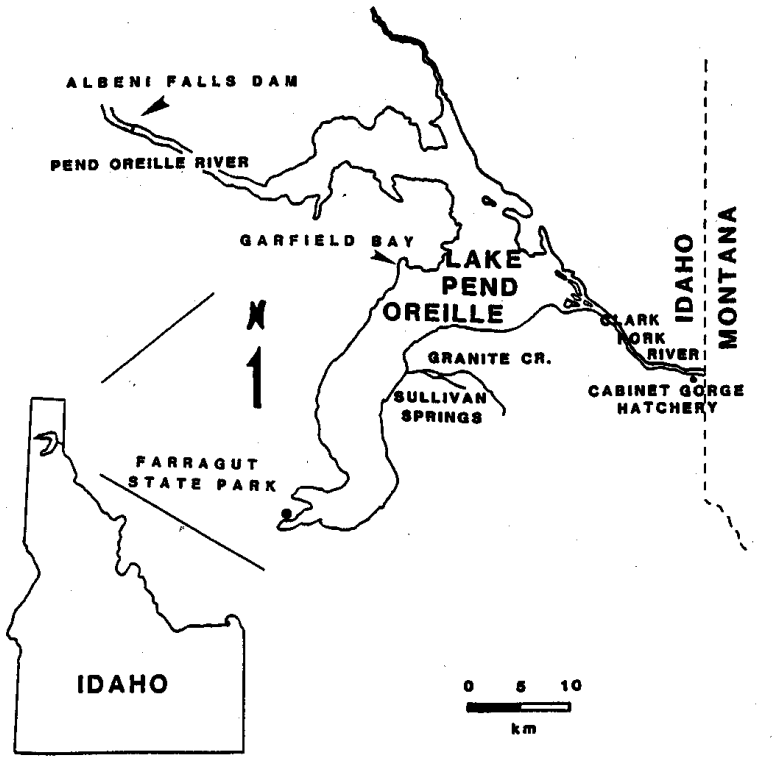

FIGURE 1.-Map of Lake Pend Oreille, Idaho with locations of kokanee stockings.

tion was to evaluate hatchery contributions to the age-0 cohort of kokanees in Lake Pend Oreille, to determine postrelease survival to near the end of the first year of growth, and to assess factors associated with survival. This evaluation was done by releasing kokanees into the lake during June or July and sampling the year-class with a midwater trawl during late August or early September. Postrelease survival to autumn trawling was expected to be a function of number of days at large; our central objective was to determine if factors other than days at large (e.g., food availability) contributed to the variability measured in postrelease survival. If other factors were identified, we anticipated that the timing and location of kokanee release could be managed to optimize postrelease survival.

Study Area

Lake Pend Oreille (Figure 1) is the largest lake in Idaho; it has a surface area of 38,300 ha, a mean depth of 164 m, and a maximum depth of 351 m. Mean surface elevation of the lake is 629 m. Coldwater habitat (area occupied by salmonids) is approximately 22,600 ha. The Clark Fork River is the lake's largest tributary, and outflow from the lake forms the Pend Oreille River.

Pend Oreille is a temperate, oligotrophic lake. During May-October, temperatures average approximately 9°C in the upper 45 m (Rieman 1977; Bowles et al. 1991). Thermal stratification typically occurs from late June to September. Mean May-October water transparency, measured with Secchi disk, usually ranges from 5 to 11 m (Paragamian and Ellis 1994). Operation of Albeni Falls Dam on the Pend Oreille River keeps the lake level stable at 628.4 m during July-September and reduces lake level to about 625.3 m during November-March.

Methods

Our methods focused on (1) estimating abundance and survival of age-0 kokanees released according to seven spatially and temporally differentiated stocking strategies, and determining their contributions to the population of age-0 kokanees in Lake Pend Oreille; (2) recognizing spatial and temporal distributions of zooplankton in the lake; (3) measuring water temperature and determining the timing and extent of thermal stratification; and (4) identifying stocking strategies conducive to increased postrelease survival to autumn.

Kokanee Releases

During 1987-1992, we evaluated seven release strategies involving five release locations and two

TABLE 1.-Location, stocking chronology, number released, and mean total length (TL) of age-0 kokanees stocked into Lake Pend Oreille, Idaho, 1987-1992.

Release site, year	Stocking date	Fish stocked Number	Mean TL (mm)
Clark Fork River			
1988	Jun 15	3,141,000	51
1989	Jun 21	3,513,000	46
1990	Jun 21	3,400,000	50
1991	Jun 26	2,610,000	49
Clark Fork River			
1987	Jul 22-27	3,013,700	52
1988	Jul 11-14	1,297,000	48
1989	Jul 17-19	984,000	49
1992	Jul 7	1,123,600	55
Open water, north			
1988	Jun 27	1,607,000	46
1989	Jun 29	1,256,000	46
Open water, south			
1988	Jul 26	1,570,000	51
1989	Jul 26	1,428,000	56
Sullivan Springs			
1987	Jul 7-29	2,847,300	52
1988	Jul 11-14	5,139,000	49
1989	Jul 11-13	3,538,000	51
1990	Jul 10-12	3,200,000	50
1991	Jul 9-10	2,570,000	50
1992	Jul 14-15	3,440,000	60
South shoreline			
1989	Jul 27-28	1,024,000	55
1990	Jul 24-25	1,100,000	50
Garfield Bay			
1992	Jun 30	970,440	51

release times (Table 1). Each year 5.0 million to 13.0 million kokanees, ranging from 46 to 60 mm in mean total length (TL), were released early (June) or late (July). All hatchery fish were progeny of adults from Lake Pend Oreille captured at tributary trapping facilities, primarily at Sullivan Springs, a tributary of Granite Creek (Figure 1). Effectiveness of each release strategy was evaluated by trawling in late August or early September.

Clark Fork River.-Some 1.0 million to 4.7 million age-0 kokanees were released each year into the Clark Fork River to establish a spawning run to Cabinet Gorge Fish Hatchery (Table 1). With the aid of nets and electrofishing, we estimated travel time and speed for kokanees to reach the mouth of the river after each release from the hatchery, except in 1990.

In June 1988-1991, 2.6 million to 3.5 million kokanees averaging 46-51 mm TL were released at 2030 hours through the Cabinet Gorge Hatchery fish ladder into Clark Fork River (Table 1). Releases were scheduled to coincide with maximum nonspill discharge (approximately 800 m^3/s) from Cabinet Gorge Dam. This maximized flushing velocities without creating gas supersaturation problems. These flows were provided by spring snowmelt and regulated by WWP at the dam; in 1990 and 1991, however, spring flows far exceeded the targeted flow (Table 2).

TABLE 2.-Clark Fork River discharges during June and July kokanee releases from the Cabinet Gorge fish hatchery, 1987-1992, and speeds of fish travel to Lake Pend Oreille.

Year	Release group	Discharge (m3/s) 24-h range	Mean over 3 h at release (m^3/s)	Travel speed (km/h)
1987	Jul	99-694	569	5.0
1988[a]	Jun	100-920	809	
1989[a]	Jun	900-1,842	1,024	7.3
1990	Jun	1,480-1,842	1,842	7.0
1991	Jun	99-1,984	1,984	
1992	Jul	91-652	634	6.1

[a] Fish released in July were barged down the Clark Fork River.

In July 1987-1989 and 1992, 1.0 million to 3.0 million kokanees averaging 46-55 mm TL were released. They were barged down the Clark Fork River in 1988 and 1989 and released through the hatchery ladder in 1987 and 1992 (Table 1). Barging was used in an attempt to avoid predation by northern squawfish *Ptychocheilus oregonensis* during kokanee emigration. Barged kokanees were released during daytime into Lake Pend Oreille 100 m beyond the mouth of the river. Approximately 2 h was required for each trip of a 8.5-m pontoon barge equipped with two circular tanks that carried 8.8 m^3 of water each. The tanks were aerated and plumbed to provide circulating river water; each tank could contain 18 kg/m^3 of kokanees.

Open water.--We released approximately 3.2 million kokanees during the daytime in 1988 and 2.7 million in 1989 to evaluate open-water release strategies (Table 1). We hypothesized that open-water releases would allow hatchery kokanees to avoid shoreline predators and be in immediate contact with zooplankton forage. Release strategies included June releases into a northern section of Lake Pend Oreille and July releases into a southern section. The June release occurred before thermal stratification. Hatchery kokanees were loaded (208 kg/m^3) into fish transport trucks, driven onto flatbed construction barges, and released in open water approximately 2 km from the nearest shoreline.

Sullivan Springs.--In July 1987-1992, 2.6 million to 5.1 million kokanees averaging 49-60 mm TL were transported (55-59 kg/m^3) by truck from Cabinet Gorge Hatchery to Sullivan Springs Creek

(Table 1). These releases occurred during daylight. One purpose of this release was to ensure continued adult returns to the hatchery spawning station on this spring-fed tributary.

South shoreline.--About 1 million kokanees were stocked along the southern shoreline in July 1989 and 1990 (Table 1). Fish length averaged 55 mm in 1989 and 50 mm in 1990. Kokanees were transported (50-74 kg/m^3) by truck to Farragut State Park and released at dusk.

Garfield Bay.--We stocked fish in Garfield Bay in 1992 to test if a nutrient-rich, warmwater embayment (Rieman 1977) would benefit kokanee survival. Kokanees were transported in hatchery trucks at about 55 kg/m^3. We released about 1 million kokanees, averaging 51 mm TL, from the dock of a marina at 2030 hours (Table 1). Because the end-June release date did not match the June or July stocking times elsewhere and because Garfield Bay is a unique environment, these fish were not used in analyses of stocking time and survival.

Abundance of Age-0 Kokanees

We determined abundance of age-0 kokanees in Lake Pend Oreille by collecting fish with a midwater trawl during the last week of August or first week of September (autumn) each year. We trawled at night during the new moon to optimize capture efficiency. The net was 13.7 m long and had a 3-m X 3-m mouth and stretched mesh sizes graduating from 32, 25, 19, and 13 mm in the body of the net to 6 mm in the cod end. We towed the trawl at 1.5 m/s at depths calibrated with a depth sounder. Each oblique haul sampled the entire vertical distribution of kokanees, as determined from echograms produced by a Ross 200-angstrom depth sounder with two hull-mounted transducers (22° and 8° beam angles). The vertical distribution of kokanees was divided into 3.5-m layers; usually three to seven layers were adequate. A standard 3.5-min tow was made in each layer, sampling 2,835 m^3 of water over a distance of 315 m. Total volume of water sampled for each trawl haul varied from 8,496 to 19,824 m^3, depending on the vertical distribution of kokanees.

We used a stratified systematic sampling design to estimate kokanee abundance and density. We divided Lake Pend Oreille into six strata. The area of each stratum was calculated for the 91.5-m contour; however, the area of the northernmost stratum was calculated for the 36.6-m contour because of shallower water. The 91.5-m contour was used because it defines the pelagic area of the lake where kokanees are found during late summer. Six transects were systematically selected within each stratum and one haul (sample) was made along each transect. Total sample was 36 hauls/year.

Fish numbers per transect (haul) were divided by transect volume, and the age-specific and total numbers of kokanees in each stratum and in the lake were calculated with standard expansion formulae for stratified sampling designs (Scheaffer et al. 1979). Kokanee population estimates (total and by stratum) were divided by respective lake surface areas to calculate kokanee densities (number/ha) for each age-class.

Survival of Stocked Age-0 Kokanees

Survival of age-0, hatchery-reared kokanees was determined from population estimates of individual release groups and calculated as a proportion of the number of fish released. Hatchery groups were differentiated from wild fish and from each other by a combination of diet-induced oxytetracycline marks, date-of-release marks, and daily growth increments on sagitta otoliths. Age-0 hatchery kokanees released into the lake developed distinct release marks on their otoliths, which differentiated them from wild fish (Paragamian et al. 1992).

Sampling Zooplankton

We sampled the zooplankton community in northern, central, and southern sections of Lake Pend Oreille starting 2 years before the stocking evaluation. Five systematic samples were collected monthly from each stratum during May-October 1985-1992. Samples were also collected from the delta area of the Clark Fork River in 1985-1989 and from Garfield Bay in 1992. We collected samples with a 0.5-m-diameter ring plankton sampler equipped with a 130-µm-mesh net and bucket and calibrated by a Kahl Scientific flowmeter. Vertical hauls from 27.4-m depths to the surface were made by raising the sampler approximately 0.5 m/s with an electric winch. The samples were diluted and subsampled by standard methods (Edmondson and Winberg 1971) and zooplankters were counted by genus. Counts were standardized by volume of water filtered to determine zooplankton densities. Zooplankters were measured at 100X magnification, and mean lengths were calculated for each month and lake stratum for 1985-1990 and 1992. We used analysis of variance (ANOVA) to compare zooplankton densities both spatially and temporally.

TABLE 3.--Autumn abundances of age-0 kokanees stocked in Lake Pend Oreille, calculated from trawl catches (CI is confidence interval), and estimated survival as percentages of the fish stocked.

				Autumn population size		Survival	
Brood year	Year stocked	Total stocked (millions)	Trawl total catch	Estimate	90% CI (% of estimate)	Estimate	SE (% of estimate)
1986	1987	5.86	107	797,661	15.8	13.6	2
1987	1988	13.13	485	3,682,216	10.9	28.7	3
1988	1989	11.74	289	2,246,064	15.0	19.1	3
1989	1990	7.70	209	1,562,451	11.9	20.0	5
1990	1991	5.18	137	1,052,029	23.6	20.7	5
1991	1992	5.47	278	2,125,261	17.1	38.5	7

Temperature

Water temperature was measured monthly from May through November, 1985-1992, at one site in the southern section of the lake. Technicians measured temperatures with a probe from the surface to 60-m depths at 1-m intervals for the first 5 m, and at 5-m intervals thereafter. When a dramatic change in temperature was noticed within a 5-m depth interval, frequency of measurement was increased to 1-m intervals. Mean daily air temperatures were obtained from the Idaho Department of Agriculture. Daily and monthly minimum and maximum means of air temperature at Bayview, Idaho, were used to calculate degree-days for 1985-1992.

Survival Relationships

We used simple regression analysis to describe relationships between postrelease survival of age-0 kokanees and release strategies, mean total zooplankton, zooplankton body lengths, zooplankton densities (total and by genus), and lake temperatures. We used multiple-regression analysis to determine if survival was affected by days at large and total zooplankton densities at release. Regression and ANOVA techniques were used to relate and compare air temperature (in degree-days) and thermal stratification to zooplankton density. We used repeated-measures ANOVA to compare mean postrelease survival between June and July releases and among the five release locations, and we used Tukey's studentized test to determine differences between individual means.

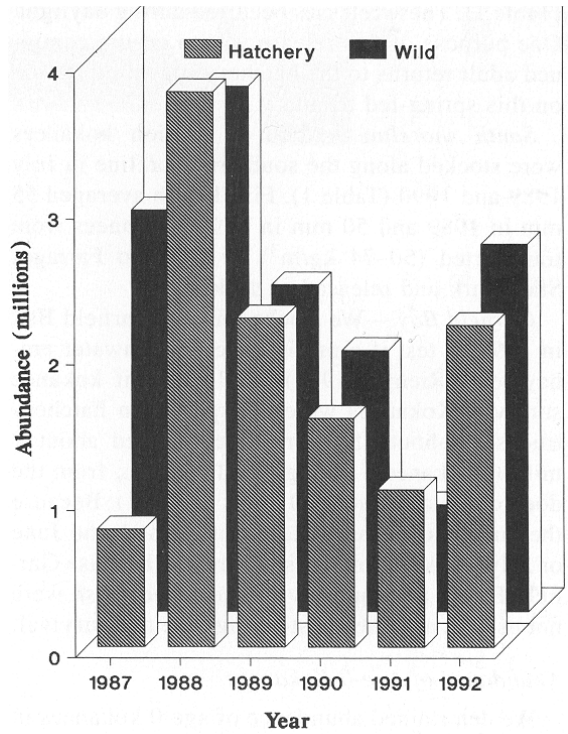

FIGURE 2.-Estimated abundances of wild and hatchery age-0 kokanees in Lake Pend Oreille, 1987-1992.

Results

Age-D Kokanee Abundance and Distribution

Our trawl catches of age-0 hatchery kokanees ranged from 107 fish in 1987 to 485 in 1988 (Table 3). Estimated abundances ranged from 35/ha in 1987 to 163/ha in 1988. Contribution of hatchery age-0 kokanees ranged from 0.80 million in 1987 (22% of total) to 3.7 million in 1988 (51% of total); the greatest proportional contribution by hatchery fish was 59% in 1991 (Figure 2). The contribution of wild age-0 kokanees ranged from 0.7 million in 1991 to 3.6 million in 1988 (Figure 2).

We found hatchery kokanees were more uniformly distributed throughout the lake than wild fish. However, highest densities were near release sites. For example, kokanees released on the southern shoreline were most common at the southern end of the lake, fish released into the Clark Fork River were most common at the north end of the lake, and fish released at Sullivan Springs were associated with the central portion of the lake. In general, the longer hatchery kokanees were in the lake before trawling occurred, the farther they dispersed from the release site. Wild kokanees were

TABLE 4.-Autumn abundances and survival of age-0 kokanees stocked in Lake Pend Oreille, by release group (CI is confidence interval; ND means no data).

Stocking site	Year	Stocking period	Trawl total catch	Autumn population size	Survival	
					Estimate	90% CI (% of estimate)
Clark Fork River	1988	Jun	116	921,781	27	4
	1989	Jun	81	632,340	18	4
	1990	Jun	62	510,000	15	3
	1991	Jun	61	477,630	18	4
Clark Fork River	1987	Jul	ND	292,329	10	
	1988	Jul	50	376,130	29	5
	1989	Jul	19	147,600	16	5
	1992	Jul	43	364,384	32	9
Open water, north	1988	Jun	38	353,540	22	6
	1989	Jun	7	62,800	5	2
Open water, south	1988	Jul	82	565,200	36	4
	1989	Jul	51	357,000	25	5
Sullivan Springs	1987	Jul	ND	512,514	18	
	1988	Jul	198	1,490,310	29	4
	1989	Jul	102	742,980	21	3
	1990	Jul	99	742,402	23	3
	1991	Jul	78	593,626	23	5
	1992	Jul	179	1,319,135	38	7
South shoreline	1989	Jul	39	276,480	27	9
	1990	Jul	48	308,000	28	4
Garfield Bay	1992	Jun[a]	56	412,875	43	6

[a] End-June date was intermediate between other June and July stocking dates.

found in greater abundance in the southern portion of the lake.

Postrelease Survival

Survival of hatchery-reared kokanees from time of release in June or July to sampling in late August or early September averaged 23% for 1987-1992 and ranged from 14% in 1987 to 39% in 1992 (Table 3). Survival estimates for 1988 and 1992 were similar and significantly higher ($P < 0.05$) than in other years. Survival of age-0 kokanees by release group ranged from 5% for a June 1989 open-water release to 38% for a July 1992 release at Sullivan Springs (Table 4). The highest survival was 43% for the unique release in Garfield Bay (Table 4).

Emigration

Kokanees emigrating from Cabinet Gorge Hatchery down the Clark Fork River reached the lake in 3-5 h. About 98% of the surviving kokanees reached the lake during the first night after release at about 2030 hours; the remainder reached there the second night. Average travel speeds ranged from about 5.0 km/h in 1987 to 7.3 km/h in 1989 and generally increased with increasing discharge (Table 2).

Zooplankton Community

Our net sampled six genera in the zooplankton community of Lake Pend Oreille: *Cyclops, Diaptomus, Epischura, Bosmina, Daphnia,* and *Diaphanosoma.* Mean annual (May-October) zooplankton densities ranged from 12 organisms/L in 1991 to 25/L in 1992 (Table 5). Average monthly zooplankton density ranged from 7 organisms/L in May to 28/L in August (Figure 3). Copepods were more abundant than cladocerans throughout the study. The copepods *Cyclops* and *Diaptomus* were the most abundant zooplankters. *Epischura* was the least abundant copepod during our study, averaging 0.2/L. Cladocerans were extremely uncommon except in August, when they were found in most samples and in all the samples from Garfield Bay. *Daphnia* was the most abundant cladoceran followed by *Bosmina* and *Diaphanosoma.*

We found total zooplankton densities to be statistically similar ($P > 0.10$) among northern, southern, and central sections of Lake Pend Oreille. In general, zooplankton densities in the Clark Fork River delta were significantly lower ($P < 0.10$) than in the rest of the lake, but *Bosmina* and *Daphnia* densities were significantly higher near the delta than elsewhere. In Garfield Bay,

Table 5. -- Mean midday densities of cladocerans and copepods (number/L above depths of 27.4 m) in Lake Pend Oreille, Idaho. Samples were collected during May-October 1985-1992; standard deviations are in parentheses.

	Cladocerans			Copepods			
Year	Bosmina	Daphnia	Diaphanosoma	Cyclops	Epischura	Diaptomus	All[a]
1985	0.37	0.38	0.07	9.12	0.04	6.26	19.30
	(0.74)	(0.57)	(0.14)	(6.97)	(0.10)	(3.20)	(11.64)
1986	0.03	1.27	0.01	6.73	0.01	5.09	13.13
	(0.06)	(2.61)	(0.04)	(4.19)	(0.02)	(3.45)	(8.66)
1987	0.59	1.08	0.04	8.87	0.04	4.36	15.04
	(0.76)	(1.57)	(0.08)	(5.19)	(0.09)	(2.32)	(7.18)
1988	0.15	0.70	0.17	13.23	0.02	7.46	21.72
	(0.27)	(1.51)	(0.39)	(8.13)	(0.03)	(4.86)	(12.75)
1989	0.99	0.71	0.34	11.09	0.02	7.45	20.59
	(2.77)	(1.58)	(0.76)	(8.74)	(0.03)	(4.43)	(12.19)
1990	0.27	0.32	0.12	9.17	0.03	8.06	17.99
	(0.34)	(0.54)	(0.29)	(6.36)	(0.05)	(5.62)	(11.48)
1991	0.19	0.35	0.07	6.71	0.02	5.63	12.11
	(0.59)	(0.74)	(0.19)	(10.44)	(0.03)	(4.15)	(7.31)
1992	0.08	1.05	0.13	14.81	0.01	9.24	25.17
	(0.26)	(2.23)	(0.29)	(9.27)	(0.02)	(7.59)	(16.23)

[a] Calculated independently as the total of all genera.

cladocerans were sampled earlier and were more abundant at that time than in other sections of the lake, but total zooplankton densities were lower.

The largest zooplankton in Lake Pend Oreille during this study was *Epischura*, which averaged 1.90 mm. *Daphnia thorata* averaged 1.16 mm, *Daphnia galeata* 1.01 mm, *Diaphanosoma* 0.94 mm, *Diaptomus* 0.85 mm, *Cyclops* 0.72 mm, and *Bosmina* 0.37 mm. The largest daphnias sampled during this study were in Garfield Bay in 1992.

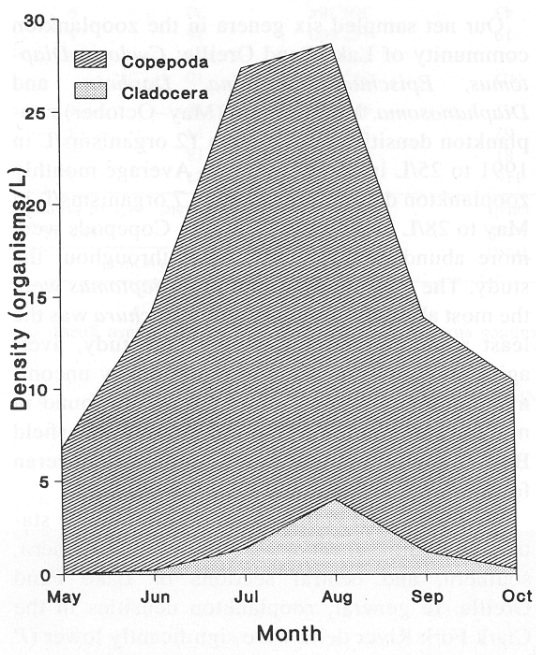

FIGURE 3.--Temporal distribution of copepod and cladoceran densities in Lake Pend Oreille, May-October 1985-1992.

Water Temperature

Surface water temperatures of Lake Pend Oreille ranged from about 6°C in May to 21°C in August during 1985-1992. Thermal stratification usually began in July and extended into October. In 1988, 1992, and (to a lesser extent) 1987, thermal stratification began in June. The most rapid thermal stratification occurred in 1992. The slowest rate of stratification occurred in 1989 and stratification broke down quickly. At peak stratification in August or September, the metalimnion began at depths ranging from 12 to 15 m, and epilimnetic water temperatures averaged 16-19°C.

Survival Factors

Days in Lake Pend Oreille.--We found a weak association (Figure 4) between survival of stocked kokanees and days at large (number of days from release to autumn trawling) in 1988 (r^2 = 0.61, N =5, P = 0.12) and in1989 (r^2 = 0.44, N = 6, P = 0.15). Because there were only two or three releases in each of the other years, we were unable to evaluate within-year survival statistically. When we pooled all of the years we could not

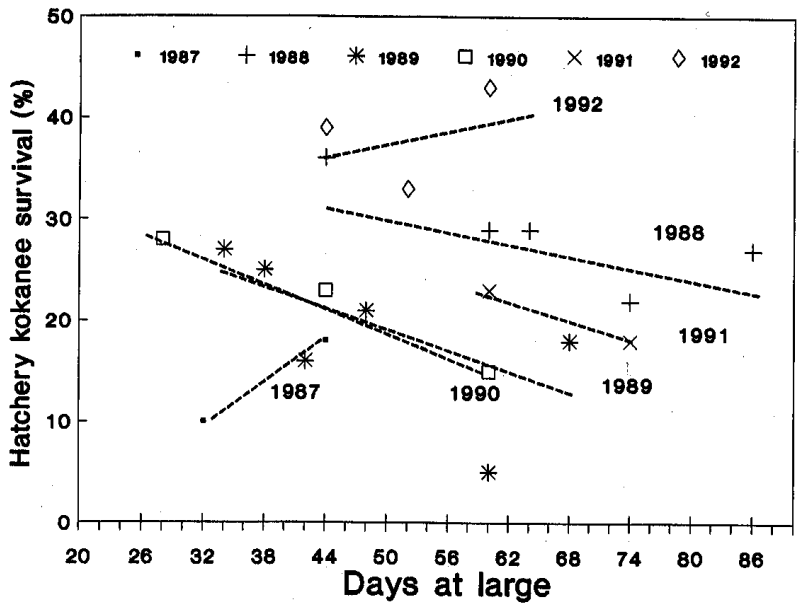

FIGURE 4.--Survival of age-0 hatchery kokanees in Lake Pend Oreille versus days at large (release date to autumn trawling). Regression lines have been fitted to 1988 and 1989 data, trend lines to the 1987 and 1990-1992 data. Zooplankton densities were highest in 1988 and 1992.

detect a statistical relation between days at large and survival ($r^2 < 0.01$, $P = 0.71$). When data from 1988 and 1989 were fitted with a regression line and the remaining years with trend lines, the years of highest fish survival (1988, 1992) were also the years of highest zooplankton density (Figure 4).

Stocking time and location.--We used 1988-1991 data to assess the effect of stocking time on survival, these being the only years with both June and July releases. Fish released in July had significantly higher survival ($P < 0.02$) than those released in June; average survival was 26% for July releases and 17% for June releases. We could not detect a difference in survival between stocking sites ($P > 0.71$) for 1988-1991. However, the power of our study design was limited because a shortage of fish prevented adequate replicate stocking after 1989.

Temperature and zooplankton relationships.--We found air temperature (degree-days) to be closely related to stratification of Lake Pend Oreille, but we were unable to detect strong relationships between air temperature or lake stratification and zooplankton density. Greatest depth achieved by the epilimnion was significantly related to May and June degree-days ($r^2 = 0.41$, $P = 0.09$). The best air temperature predictor of May-October zooplankton density was the sum of May and June degree-days; it resulted in a positive relationship but was not significantly related to total zooplankton density ($r^2 = 0.35$, $P = 0.12$).

Zooplankton and kokanee survival.--Several relations between postrelease survival of age-0 kokanees and zooplankton density were identified. Survival of the combined release of all age-0 kokanees each year was significantly correlated with yearly mean total zooplankton density ($r^2 = 0.65$, $P = 0.05$) and with total mean zooplankton density during the approximate time of release ($r^2 = 0.29$, $P = 0.01$; Figure 5).

We detected significant contributions of *Diaphanosoma abundance* ($r^2 = 0.33$, $P = 0.05$) and *Daphnia* abundance ($r^2 = 0.20$, $P = 0.10$) to survival of stocked kokanees. *Diaphanosoma* and *Daphnia* were seldom found in plankton samples before July, but were present during July kokanee releases. Survival of age-0 kokanees was also significantly related to mean body length of *Daphnia* ($r^2 = 0.69$, $P = 0.01$; Figure 5), although *Daphnia* body length was highly correlated with *Daphnia* density ($r^2 = 0.75$, $P = 0.03$). We could not detect a statistical relationship between survival of age-0 kokanees and mean lengths of other zooplankton genera.

Zooplankzon, release time, and survival of kokanees.--We divided kokanee stockings into June (early) and July (late) releases and ranked zooplankton densities within each subset (Figure 6). Survival increased as total zooplankton density in-

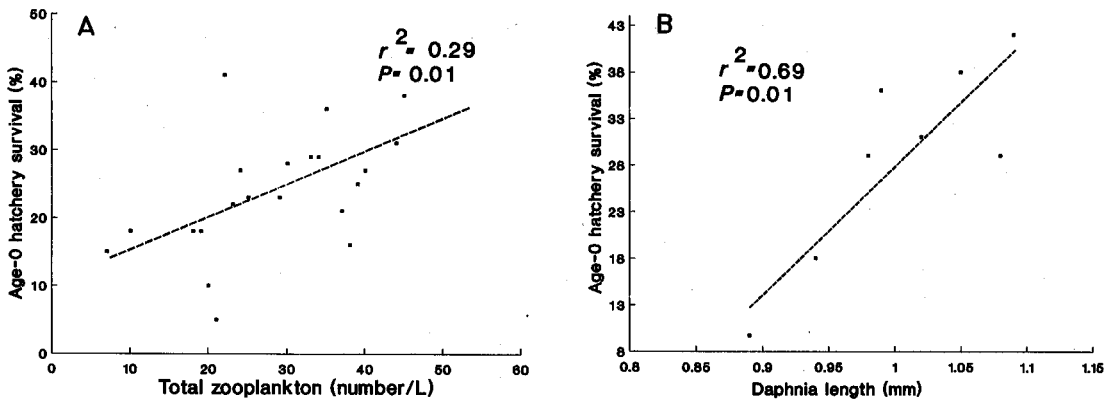

FIGURE 5.-Regressions of age-0 hatchery kokanee survival (all release groups) on (A) total zooplankton density during month of release, 1987-1992, and (B) mean length of *Daphnia* at each site (when present) in month of release, 1987-1992.

creased (r^2 = 0.62, P < 0.01; ANOVA, F = 13.10, df = 1, 9). The two 1989 release groups (July Clark Fork River and June open water releases) had unexpectedly low survival (Table 4), but these results did not deny the overall trend.

July releases coincided with higher densities of zooplankton (Figure 3). Kokanees stocked in June appeared to survive well when total zooplankton densities were at least 24/L, as they were in 1988 (Figure 6).

Zooplankton, days at large, and survival of kokanees.--We used stepwise multiple-regression analysis to test the hypothesis that survival was related both to timing of the release, measured as the number of days at large, and to the total zooplankton density at the time of release. We confirmed that zooplankton density made a major contribution, whereas days at large made only a minor contribution. Total zooplankton, entered first in the regression, provided a significant correlation (P < 0.01) and accounted for 45% of the variation in kokanee survival. The addition of days at large to the model explained an additional 4% of the variation (R^2 = 0.49, P < 0.01). When days at large alone was regressed on survival, we could not detect a significant correlation (r^2 = 0.01, P = 0.71).

To test the relationship for an individual release strategy, we repeated the analysis with Sullivan

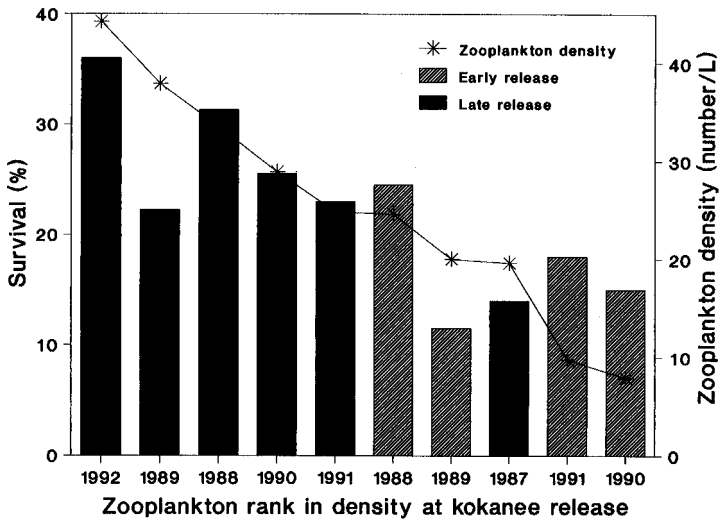

Figure 6.--Total zooplankton densities ranked from highest to lowest (left to right) during June (early) and July (late) releases of age-0 kokanees, and average survival for each temporal release of kokanees, 1987-1992.

Springs data, which represent the most consistent release numbers and times. Again, we found a significant relationship between kokanee survival and total zooplankton density (r^2 = 0.61, P = 0.07), but addition of days at large to the multiple-regression model did not improve this relation.

Discussion

Hatchery Contributions

We believe that releases from Cabinet Gorge Hatchery have enhanced the abundance of age-0 kokanees in Lake Pend Oreille. During 1978-1986, before Cabinet Gorge Hatchery was capable of full production, the fraction of hatchery fish in the population averaged less than 20% (Paragamian and Ellis 1994), the only substantial contribution of hatchery kokanees-about 50%-occurred in 1982 (Paragamian and Ellis 1994). During 1987-1992, with the facility in full production, hatchery contributions exceeded 50%. This enhancement may have resulted from improvement in postrelease survival, because release strategies were refined from 1986 to 1988 (IDFG, unpublished data). For example, the number of fish released increased from only several hundred thousand in some years to 13 million in 1988; average fish size at release increased from 33 to 50 mm; Clark Fork River releases were timed to coincide with flushing flows; and open-water releases were implemented. Although it was not possible to determine the relative contributions of these individual strategies, we believe the changes helped provide a fivefold increase in postrelease survival and a hatchery contribution equaling wild age-0 production in Lake Pend Oreille.

From 1988 to 1990, release strategies were held relatively constant to evaluate year effects on postrelease survival. During this period, hatchery fish continued to make up approximately 50% of age-0 kokanee abundance in Lake Pend Oreille, and combined postrelease survival to autumn trawling fluctuated between 19 and 29%. Although benefits to age-0 kokanee abundance in Lake Pend Oreille were realized, long-term hatchery contributions to the kokanee fishery, the adult stock, and abundance of naturally produced kokanees are uncertain (Paragamian and Ellis 1994).

Survival Factors

Postrelease survival of age-0 kokanees to autumn trawling (combined strategies) was correlated with mean May-October zooplankton density. High zooplankton densities were associated with warm spring air temperatures and rapid stratification of Lake Pend Oreille. May was the most important month for warming of the lake, then June. The highest accumulation of May degree-days occurred during 1988 and 1992, years with the best survival of hatchery kokanees. In these years, the epilimnion extended to its greatest depth and thermal stratification occurred in June. Thermal stratification did not occur until July during other study years. We predict that survival will likely fluctuate between 25 and 30% if optimal release strategies are continued.

Although the power of our design was inadequate to detect differences in survival among release sites during 1988-1991, we did find that-because of higher zooplankton densities-July release groups survived significantly better into autumn than June release groups. Only a small proportion of the survival difference between June and July releases was explained by days at large. Zooplankton densities and the size of *Daphnia* appear to be the most important factors determining survival of kokanees from release to autumn. Zooplankton densities at the time of release explained the majority of variability accounted for in postrelease survival of kokanees. In general, July release strategies will maximize survival to the end of the first growing season. But kokanees can be released in June if zooplankton densities are sufficiently high to support survival that will meet management goals. Densities of *Diaphanosoma* and *Daphnia* cladocerans were also correlated with postrelease survival of kokanees. From work at Odell Lake, Oregon, Lewis (1971, 1972) reported that year-class abundance of stocked kokanees was established in their first year of life, that abundance was related to zooplankton density, that *Daphnia longispina* was an important food item, and that the best time for release was June-August during peak zooplankton abundance.

Cladocerans are important food items of young kokanees in Lake Pend Oreille (Rieman and Falter 1981) and in other waters (Martinez and Bergersen 1991). Kokanee fry forage more effectively on slow-moving cladocerans than the faster copepods (Rieman and Bowler 1980). We seldom found cladocerans in zooplankton samples before July except in Clark Fork River delta and Garfield Bay samples. Rieman and Falter (1981) found cladocerans only around shorelines and embayments prior to thermal stratification in Lake Pend Oreille during the mid-1970s.

We found a positive relationship between mean length of *Daphnia* and the survival of stocked kokanees. Kerr (1971) provided theoretical evidence

that feeding and growth of planktivores is more efficient when based on large rather than on small prey. Noble (1975) found that growth and survival of yellow perch *Perca flavescens* was directly related to abundance and size of *Daphnia* in Lake Oneida, New York. Hambright and Hall (1992) also found preferences for large *Daphnia* were high for pumpkinseeds *Lepomis gibbosa* and fathead minnows *Pimephales promelas* in a laboratory study. Size of zooplankton was also important to growth of yellow perch in Indian River Lakes in New York (Mills and Schiavone 1982). We believe high total zooplankton densities, high densities of *Diaphanosoma* and *Daphnia,* and the large size of *Daphnia* contributed to higher survival of July-released kokanees in Lake Pend Oreille.

Jaenicke et al. (1987) provided data suggesting that fry of sockeye salmon (anadromous *Oncorhynchus nerka)* in Alaskan lakes would grow and survive better if they were released in productive bays, where food production and nearshore cover were greater. Our 1992 release of kokanees into Garfield Bay, a relatively productive bay, provided our highest estimate of postrelease survival (43%). However, this release was unreplicated and the result needs validation.

Supplementation of kokanees in Lake Pend Oreille has neither increased kokanee abundance to historical levels nor restored the fishery (Paragamian and Ellis 1994). Most of the factors hindering restoration of the kokanee fishery are environmental and cannot be controlled directly by fishery managers. Simply stocking fish will not mitigate problems such as water level drawdown after spawning and the deteriorating quality of spawning substrates. However, age-0 hatchery kokanees have contributed over 50% of age-0 fish in Lake Pend Oreille and may have improved the fishery in 1991 (Paragamian and Ellis 1994). The numbers of hatchery fish available to stock each year have been inconsistent, and only short-term benefits may be provided by the hatchery program until the environmental problems are properly addressed.

Monitoring zooplankton populations can provide information on the best time to stock kokanees. Most annual releases into Lake Pend Oreille should occur in July to take advantage of peak cladoceran densities and stratified water temperatures. Releases should be made in June only if zooplankton densities are sufficiently high (at least 24/L) to insure adequate survival of kokanees to meet management objectives.

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References

Bowles, E. C., B. E. Rieman, G. R. Mauser, and D. H. Bennett. 1991. Effects of introductions of *Mysis relicta* on fisheries in northern Idaho. American Fisheries Society Symposium 9:65-74.

Edmondson, W. T, and G. G. Winberg, editors. 1971. A manual on methods for assessment of secondary productivity in fresh waters. IBP (International Biological Programme) Handbook 17.

Hambright, K. D., and R. O. Hall. 1992. Differential zooplankton feeding behaviors, selectivities, and community impacts of two planktivorous fishes. Environmental Biology of Fishes 35:401-411.

Jaenicke, H. W., M. S. Hoffman, and M. L Dahlberg. 1987. Food habits of sockeye salmon *(Oncorhynchus nerka)* fry and threespine stickleback *(Gasterosteus aculeatus)* in Lake Nunavaugaluk, Alaska, and a strategy to improve sockeye salmon survival and growth. Canadian Special Publication of Fisheries Aquatic Sciences 96:161-175.

Kerr, S. R. 1971. A simulation model of lake trout growth. Journal of the Fisheries Research Board of Canada 28:815-819.

Lewis, S. L. 1971. Life history and ecology of kokanee salmon in Odell Lake. Oregon Wildlife Commission, Federal Aid in Fish Restoration, Project F-71-R-7, Portland.

Lewis, S. L. 1972. Population dynamics of kokanee salmon in Odell Lake. Oregon Wildlife Commis-

sion, Federal Aid in Fish Restoration, Project F-71-R-8, Portland.

Martinez, P J., and E. C. Bergersen. 1991. Interactions of zooplankton, *Mysis relicta,* and kokanees in Lake Granby, Colorado. American Fisheries Society Symposium 9:49-64.

Mills, E. L., and A. L. Schiavone, Jr. 1982. Evaluation of fish communities through assessment of zooplankton populations and measures of lake productivity. North American Journal of Fisheries Management 2:14-27.

Noble, R. L. 1975. Growth of young yellow perch *(Perca flavescens)* in relation to zooplankton populations. Transactions of the American Fisheries Society 104:731-741.

Paragamian, V. L., E. C. Bowles, and B. Hoelscher. 1992. Use of daily growth increments on otoliths to assess stockings of hatchery-reared kokanees. Transactions of the American Fisheries Society 121: 785-791.

Paragamian, V. L., and V. Ellis. 1994. Kokanee stock status and contribution of Cabinet Gorge Fish Hatchery, Lake Pend Oreille, Idaho. Idaho Department of Fish and Game, Completion Report (contract DE-A 179-85BP22493) to Bonneville Power Administration, Project 85-339, Boise.

Rieman, B. E. 1977. Lake Pend Oreille limnological studies. Idaho Department of Fish and Game, Federal Aid in Fish Restoration, Project F-53-R-12, Job IV-d, Performance report, Boise.

Rieman, B. E. 1981. Kokanee-zooplankton interactions and description of carrying capacity. Idaho Department of Fish and Game, Federal Aid in Fish Restoration, Project F-73-R-3, Job V Performance report, Boise.

Rieman, B. E., and B. Bowler. 1980. Kokanee trophic ecology and limnology in Pend Oreille Lake. Idaho Department of Fish and Game, Fisheries Bulletin 1, Boise.

Rieman, B. E., and C. M. Falter. 1981. Effects of the establishment of *Mysis relicra* on the macrozooplankton of a large lake. Transactions of the American Fisheries Society 110:613-620.

Scheaffer, R. L., W. Mendenhall, and L. Ott. 1979. Elementary survey sampling, 2nd edition. Duxbury Press, North Scituate, Massachusetts.

Simpson, J. C., and R. L. Wallace. 1982. Fishes of Idaho. University Press of Idaho, Moscow.